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Studies of Planetary Extended Atmospheres

NSA Grant No. NSG-7634

Final Report

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I. Introduction

This grant has supported research into Jupiter's luminous, heavy-particle environment. The strategy has been to collect and analyze the light produced by these atoms and ions, and to construct models using basic principles of atomic, plasma and planetary physics. Our particular goals have been: (1) improved characterization of this region's physical state and composition as a basis for interpreting Galileo in situ findings; (2) identification of the governing physical processes which sustain this unique geophysical phenomenon; and (3) improved fundamental capability in emission line diagnostic sensing of other planetary or astrophysical plasmas, with particular attention to cometary problems.

Our program has stressed high resolution spectrophotometry with special capabilities: (1) Doppler shifts measuring thermal and bulk motions; (2) detections to the 1 Rayleigh emission level; and (3) photometric accuracy limited only by photon statistics. Our instrumentation has included: (a) high dispersion Cassegrain spectrographs; (b) an array of state-of-the-art photon-counting detectors; and (c) a special telescope facility optimized to reduce scattered light.

In 1982 July 1, the Principal Investigator changed his affiliation to the Space Telescope Science Institute. With a changed budgetary profile now supporting mainly UA graduate students and observing runs, the program continues with the same PI and NASA grant NAGW-383 to ST ScI.

In the NSG-7634 grant period we made scientific advances and completed two technical projects (which found dominant support under other grants but have been crucial to this research effort). The current report summarizes these achievements.

II. Scientific Research

Neutral oxygen was discovered in the Io torus and was shown to imply a major energy path from neutrals to ions to electrons [3]. Extensive neutral clouds were discussed as possibly a dominant particle and power source for the torus [4].

Neutral sodium very far from Io was shown to imply atom-ion momentum transfer collisions are important for neutral cloud morphology [7].

The [SII] line profiles at 5.9 R_J indicate non-equilibrium and much higher average ion energy than implied by a simplistic interpretation of the half-width [8].

The non-relationship between [SII] brightness and electron density at 5.9 R_J indicates the importance of charge-exchange collisions in determining torus ionization balance [12], as does the anomalous absence of OIII [13].

The failure of torus corotation at Io's orbit was discovered; it probably indicates the transfer of angular momentum from Jupiter to newly-created ions [15].

Two reviews of torus physics were published [2, 11], plus a conference review [14].

Other planetary studies published during this period included VLA observations of Io indicating no non-thermal sources [10]; and continued work on Venus thermal emission [1].

A technical paper was published on the performance of 76° blaze angle grating used in our new Cassegrain echelle spectrograph [9]. Also, a report appeared on our clean telescope dust precipitator technique [21].

Seven abstracts for papers delivered at DPS/AAS meetings are listed in the Bibliography.

III. Technical Projects

(1) R4 Spectrograph (NSF Grant AST-7916476). This new instrument has operated at the Whipple Observatory 61 cm telescope during all the bright periods January-June 1982 and February 1982. Figure 1 is a cut-away sketch of the unusual, quasi-Littrow echelle grating mount that allows all wavelengths to be observed at the blaze peak. The flexure is relatively low (Fig. 2), the optical performance is as designed: reciprocal dispersion = 1.5\AA mm^{-1} at 5800\AA and usable resolving power $>10^5$. The low resolution mode (185\AA mm^{-1}) is also operational.

Figures 3 and 4 are representative planetary spectra obtained in Spring 1982.

(2) Detectors. We have used a variety of detectors on the spectrograph this Spring - the SAO CCD, the SAO intensified Reticon, our bare Reticon, and our 3-stage image tube. These detectors have offered different advantages for different situations. Bare silicon gives high signal-to-noise, but has difficulty with low light levels. The IRET is good for low light levels, but it is one dimensional, and the current version has large-amplitude fixed pattern noise. The image tube turns a photometric plate black at low illumination, but it is not photometric. None of these systems nor the weather were entirely satisfactory last spring, but we have been able to demonstrate our method as Figures 3 and 4 show.

Our main-line detector for emission studies is the intensified CCD array from Dr. Lyle Broadfoot's laboratory. It has been operated at the telescope in February 1983. This records single photoelectrons plus provide the two-dimensional format needed to use the spectrograph's stigmatic optics for imaging along the slit.

(3) Clean telescope (NASA Grant NAGW-262). We have developed a CCD imaging protocol to document the condition of the mirror as manifested in stellar scattered light profiles. Figure 5 is such a recently-obtained profiles synthesized from greatly-varying exposures, the longest of which saturate in the inner region. The CCD was operated with no optical filter, and the expected aperture-only diffraction profile is drawn in for different wavelengths spanning the band-pass. The approximately 1-2 orders of magnitude increase in scattered light is due to dust superposed on the mirror, which was decreased by a factor two when the primary was cleaned.

Our documentation technique is able to record a stellar profile over about seven orders of magnitude in surface brightness in the distance range 1-300 arc-seconds from the central object.

The mirror has not been protected by the dust precipitator in the last months, since that unit is being refurbished for operation without any contaminating sticky surfaces. Reference (21) is a technical description of the precipitator unit, which is being developed by Dr. Stuart Hoenig.

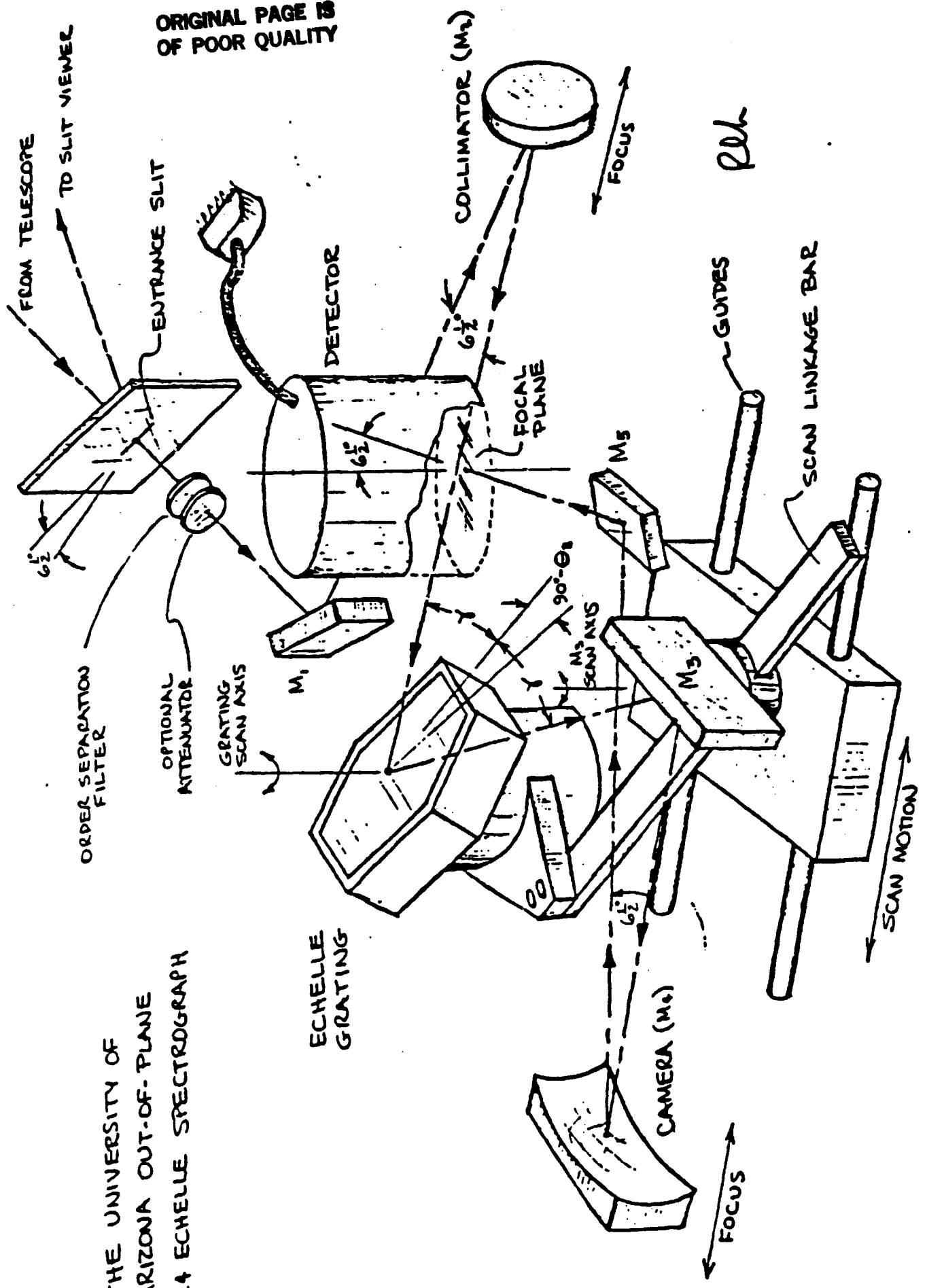
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R4 ECHELLE SPECTROGRAPH

Fig. 1 A cutaway view of the R4 echelle spectrograph optics.

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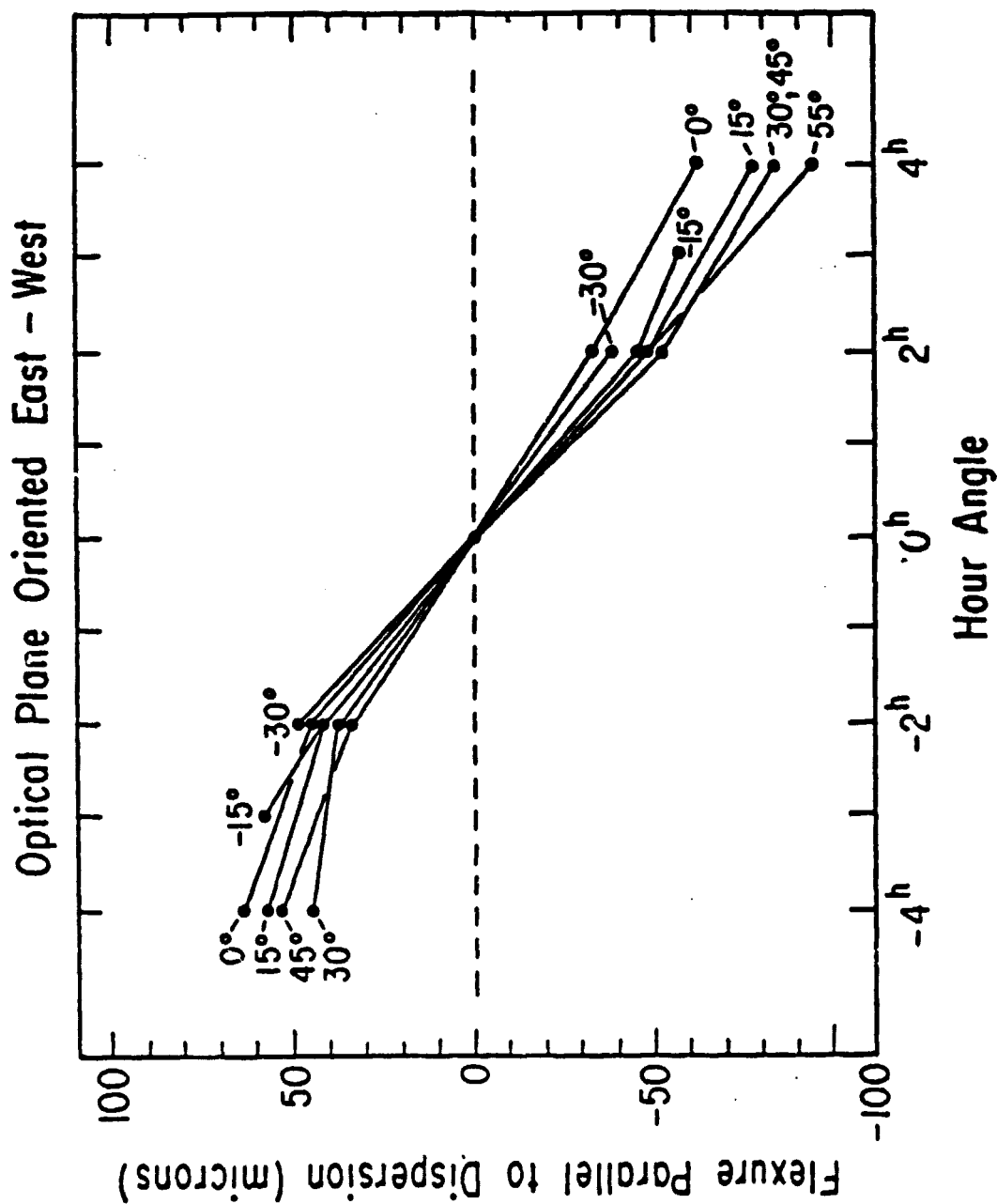


Fig. 2 Measured flexure of the R4 echelle spectrograph with telescope tracking at a range of declinations. The effect is negligible for <1/2 hour exposures.

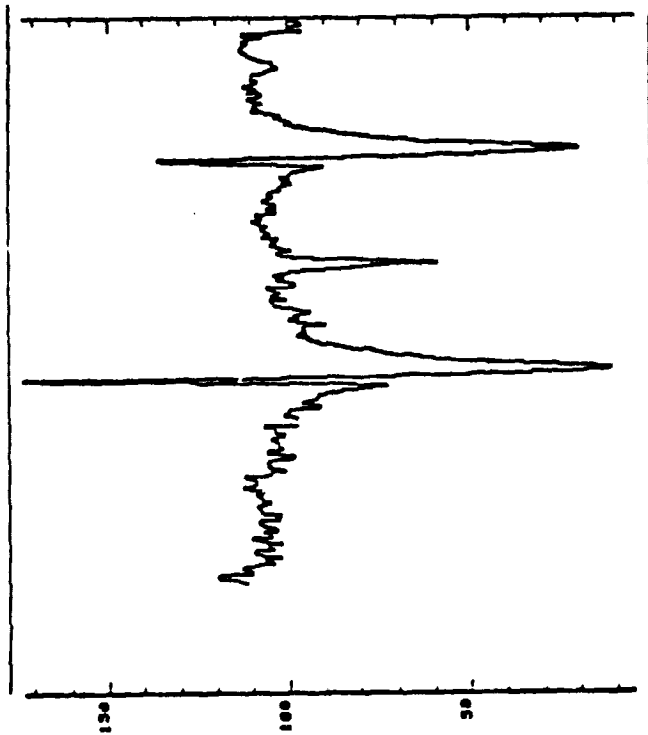


Fig. 3a This is a 50^m CCD spectrum of Io at the sodium D lines. The absorption features are the reflected solar Fraunhofer lines. The emission lines are due to resonant scattering in the sodium cloud surrounding Io. The spectrum shows only the portion of the cloud nearest Io. Adjacent spectra on the chip show cloud characteristics as a function of distance from Io.

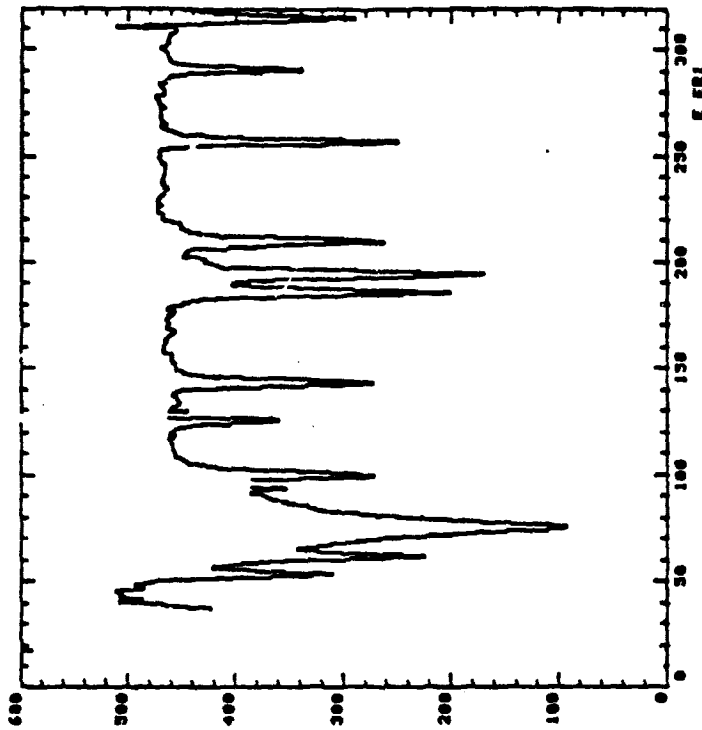


Fig. 3b A 40^m CCD spectrum of ϵ Eridanus near 6170 A containing several lines sensitive to stellar magnetism due to high atomic g-factors. The expected effect would slightly broaden the lines and requires the high S/N CCD performance.

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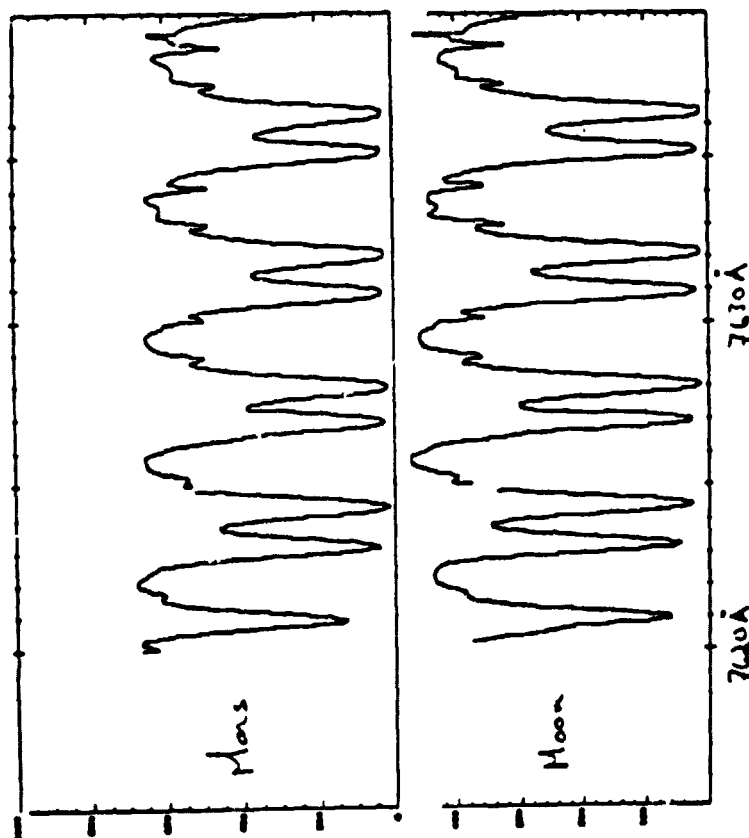


Fig. 4a Moon (a) and Mars (b) spectra in the region of the oxygen A band, taken with the SAO CCD system. The broad, deep features are absorption in the Earth's atmosphere. Absorption from O_2 on Mars should appear as a very small extra dip doppler shifted to the blue slope of each feature. The Mars spectrum is a single strip along the spectrograph dispersion at one slit height. Since the spectrograph is stigmatic, many independent spectra may be obtained from a single exposure to give spatial information.

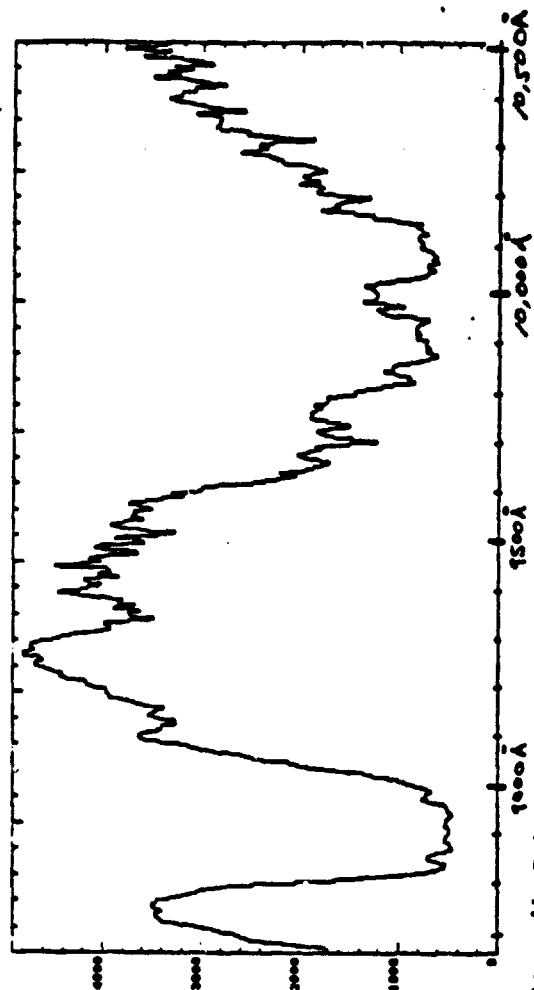


Fig. 4b This spectrum of Saturn was taken in the spectrograph's low resolution mode with the SAO CCD. The two broad absorption features are caused by methane in the atmosphere of Saturn. This spectrum, when combined with a set of H_2 spectra in the high resolution mode can give a measure of the carbon/hydrogen ratio.

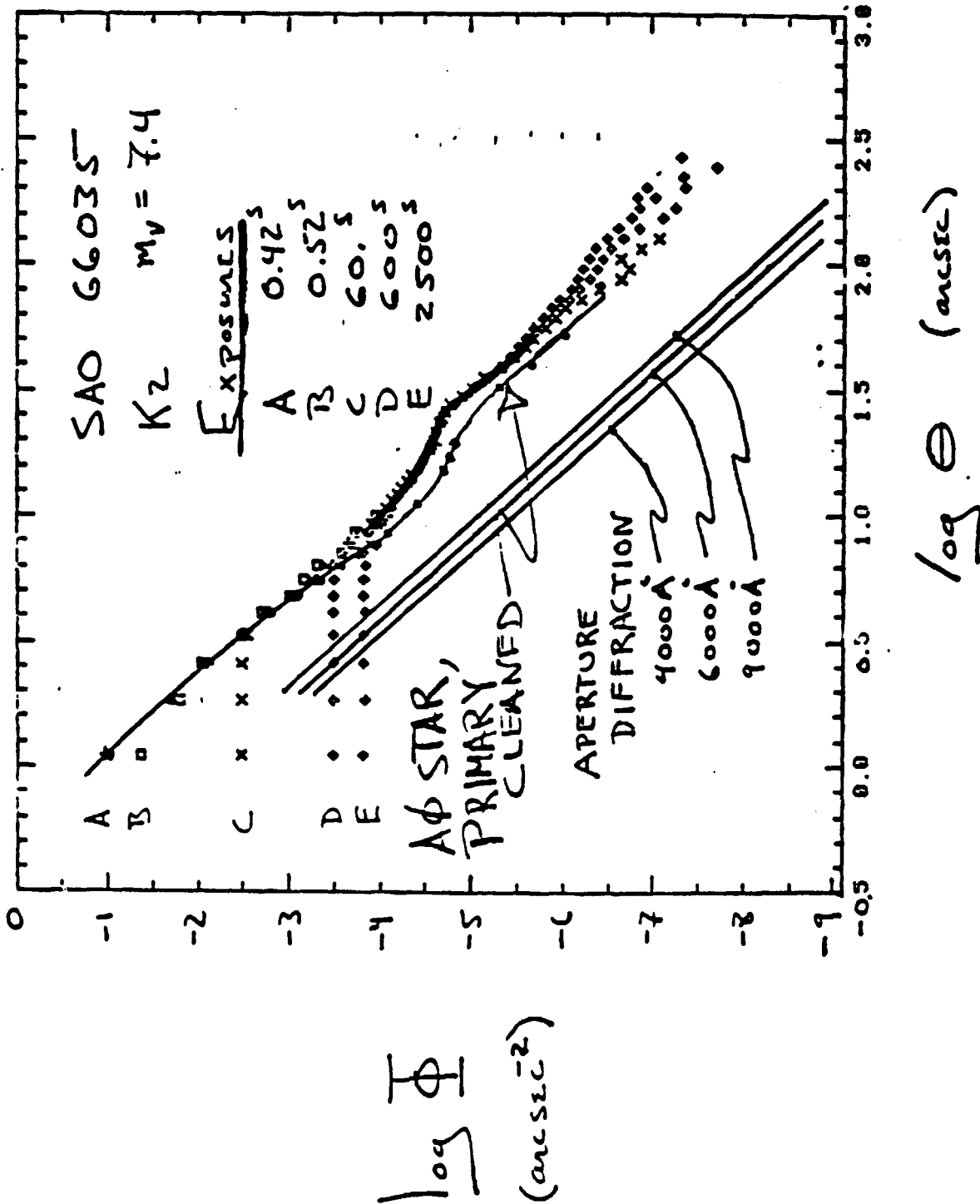


Fig. 5 A stellar scattered light profile obtained from five CCD images (A-E). Φ is the observed surface brightness normalized by the total stellar flux. Dust on the mirror surfaces causes the stellar profile to stand ~ 2 orders of magnitude above the asymptotic diffraction pattern of the telescope aperture. When the telescope primary was cleaned, the measured profile indicated a factor 2 decrease in the scattered light, as indicated.